

# Infrared Signal Detection by Upconversion Technique

Teh-Hwa Wong<sup>1\*</sup>, Jirong Yu<sup>2</sup>, Yingxin Bai<sup>1</sup> and William Johnson<sup>3</sup>

<sup>1</sup>Science Applications International Corporation, One Enterprise Parkway, Suite 300, Hampton, VA 23666-5845

<sup>2</sup>NASA Langley Research Center, MS. 468, Hampton, VA 23681

<sup>3</sup>Montana State University, Department of Physics, EPS Room 264, Bozeman, Montana 59717

\*teh-hwa.wong@ssaihq.com

**Abstract:** We demonstrated up-conversion assisted detection of a 2.05- $\mu\text{m}$  signal by using a bulk periodically poled Lithium niobate crystal. The 94% intrinsic up-conversion efficiency and 22.58% overall detection efficiency at pW level of 2.05- $\mu\text{m}$  was achieved.

**OCIS codes:** (040.3060) Infrared; (190.4410) Nonlinear optics; (190.7220) Upconversion.

## 1. Introduction

Laser operating at 2-micron wavelength offers many measurement capabilities in remote sensing applications. The ground testing and flight testing of a 2-micron Doppler Aerosol Wind Lidar system has been demonstrated in the early years of development. The wavelength of this laser also matches one absorption band of CO<sub>2</sub>, which means this lidar system can be used to monitor the concentration of CO<sub>2</sub> in the atmosphere. Currently, the detector in 2 micron lidar system is a Hamamatsu long wavelength type InGaAs PIN detector with low efficiency in the 2 micron region. It is not comparable to the high detection efficiency and low dark current of Si detector in the visible region. Our approach is to develop a Lithium niobate (PPLN) based frequency up-conversion device to efficiently convert the 2.055  $\mu\text{m}$  signal into 0.7  $\mu\text{m}$ . Then the 0.7  $\mu\text{m}$  signal can be detected by a high efficiency Si detector.

Most previous work of sum frequency generation has focused on the communication wavelength 1.55  $\mu\text{m}$  [1]. The up-conversion efficiency in this near-IR region can achieve 74% to 99%. Farther into the mid-IR region, the low transmission of the mid-IR inside PPLN and the blackbody radiation in the same spatial region cause the low up-conversion efficiency [2, 3]. Beside the bulk PPLN, there are some research works on using PPLN waveguide. Ideally the up-conversion efficiency can reach 100% in a waveguide PPLN. However, there are also limitations on the detection efficiency using a waveguide PPLN. Shentu *et.al.* studied the up-conversion of 1.95  $\mu\text{m}$  [4] by using a waveguide. The intrinsic up-conversion efficiency was 99.6%, but, the inefficient coupling lowered the detection efficiency down to 10%.

## 2. Experimental Setup

The schematic of the experimental setup for intra-cavity up-conversion is shown in Fig. 1. M3 and M4 are concave mirrors each with a radius-of-curvature of 150 mm. The 50 mm long and 5 mol% MgO-doped PPLN crystal is located inside of a 52.3 °C Teflon oven, which is mounted on top of a multi-axis stage. A CW 0.808  $\mu\text{m}$  diode laser is used to pump a 10 mm long 1% doped Nd:YAG rod in the cavity to generate unidirectionally 1.064  $\mu\text{m}$  beam. Two lenses both with 150 mm focus length were used to focus 2- $\mu\text{m}$  DFB laser beam into the cavity.

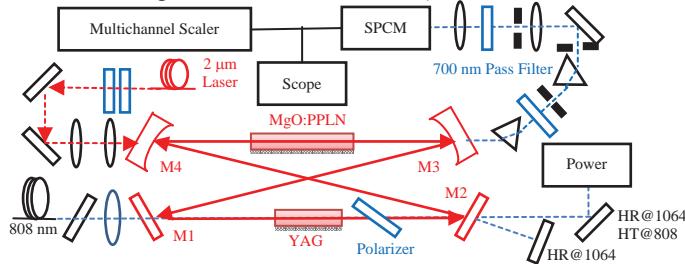


Fig. 1. Schematic of the up-conversion experimental setup

## 3. Results and Discussions

When the power of the source laser is in mW range, the 0.7  $\mu\text{m}$  signal will also be in the mW range and can be easily detected by a power meter. The power dependence of the 0.7  $\mu\text{m}$  signal on the upconverting 2  $\mu\text{m}$  signal was studied at constant 7.5 W pump laser power. The result is plotted on a log-log graph and shown in Fig. 2(a). The slope of the linear fitting is  $0.983 \pm 0.029$  which indicates that the 0.7  $\mu\text{m}$  signal strength is linearly dependent on the

2  $\mu\text{m}$  laser power. Fig. 2(b) shows the results of pump power dependance and the up-conversion efficiency for a fixed 2  $\mu\text{m}$  signal at 1.308 mW. The solid squares on the graph are the overall system detection efficiency, and solid circles are the data after correction of system transmission. The intrinsic up-conversion efficiency of PPLN can be as high as 93% at 34W pump laser power. The overall detection efficiency is 60%.

A single photon counting module SPCM-AQRH-14 was used to detect single photon signals, and the output of SPCM was sent to a Multichannel scaler/average. The 2  $\mu\text{m}$  laser output was 0.185 mW before it was attenuated with optical fiber couplers or IR Neutral Density (ND) filters. The SPCM we used has higher than normal dark count rates due to its age. The 2  $\mu\text{m}$  laser signal alone did not add to measured count rates. But, when the 0.808  $\mu\text{m}$  laser was turned on, the background level increased by 594 counts/sec. This noise was verified to be from the 0.808  $\mu\text{m}$  pump laser and not from the 1064 nm light. The 0.7  $\mu\text{m}$  signal dependence on 2  $\mu\text{m}$  laser power was also characterized at this extremely low 2  $\mu\text{m}$  power (pW). Figure 2(c) shows the relationship of 0.7  $\mu\text{m}$  signal at various 2  $\mu\text{m}$  signals by arranging the IR ND filters. The 0.963 slope in the log-log plot indicates the linear dependence of 0.7  $\mu\text{m}$  signal on pW range 2-micron power. Fig. 2(d) shows the power dependence of the 0.7  $\mu\text{m}$  signal on YAG laser power at fixed 2  $\mu\text{m}$  signal; saturation is observed at 9W YAG laser power.

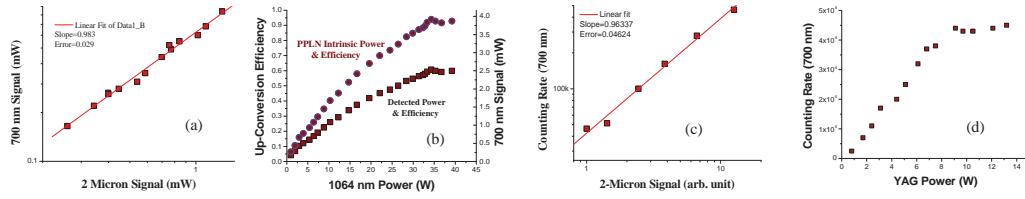


Fig. 2. (a) 2  $\mu\text{m}$  laser power dependence at mW level of 2  $\mu\text{m}$  power, (b) Pump laser power dependence at mW level of 2  $\mu\text{m}$  power, (c) 2  $\mu\text{m}$  laser power dependence at pW level of 2  $\mu\text{m}$  power, (d) Pump laser power dependence at pW level of 2  $\mu\text{m}$  power

The total detection efficiency of 0.7  $\mu\text{m}$  of the SPCM system (also including prisms, mirrors, 0.7  $\mu\text{m}$  pass filters & QE of SPCM) will be 24.02%. The initial 2-micron power is 0.1855 mW and attenuated by a factor of  $1.27 \times 10^{-9}$  by IR ND filters. Thus, the incoming 2-micron photons are at  $2.44 \times 10^5$  photons per second. The detected counting rate of 0.7  $\mu\text{m}$  is 55,000 photons per second on the counter. So the intrinsic up-conversion efficiency is 94% in the single photon counting region, with an overall detection efficiency of 22.58%.

#### 4. Conclusion

We have demonstrated up-conversion detection of a 2- $\mu\text{m}$  signal. High intrinsic conversion efficiency  $\eta = 93$  to 94% of bulk PPLN was achieved for mW level and pW level of the source laser and the overall detection efficiencies are 59.97% and 22.58% respectively. It is still be limited by propagation losses of the optics, especially the 0.7  $\mu\text{m}$  laser line pass filter. It was verified that 0.808  $\mu\text{m}$  is the source of noise in photon counting. This wavelength is so close to 0.7  $\mu\text{m}$  that it is not easy to separate them completely. Because of this difficulty, two 0.7  $\mu\text{m}$  laser line pass filters were used to block the 0.808  $\mu\text{m}$  light. But these attenuate the 0.7  $\mu\text{m}$  signal by 50%. Overall efficiency could be improved by externally pumping with a 1.06  $\mu\text{m}$  laser directly.

The linearity of the 0.7  $\mu\text{m}$  signal on the source laser (2 micron) was demonstrated at mW and pW levels; showing that the 0.7  $\mu\text{m}$  signal size can be directly connected to the CO<sub>2</sub> concentration over a wide source laser power range. Up-conversion detection by using bulk PPLN is a promising technique to extend the use of well-developed silicon detectors in to remote sensing applications.

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